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A STUDY OF END-FIRE COUPLING OF SINGLE-MODE FIBER TO TI: $LiNbO_3$ SINGLE-MODE PLANAR WAVEGUIDE

by

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A STUDY OF END-FIRE COUPLING OF SINGLE-MODE FIBER TO Ti: $LiNbO_3$ SINGLE-MODE PLANAR WAVEGUIDE

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Zhao Qinghua, Gao Junjie[1], Fan Junqing, Xu Chengjie[2]

INTRODUCTION

Most of the widely studied modulator, switch, spectrum analyzer in integrated optics use Ti-diffused $LiNbO_3$ waveguides. Improving single-mode fiber to waveguide coupling efficiency and realizing the fixed connection between them is one of the most fundamental problems.

In our experiment, a direct coupling of single-mode fiber to waveguide is used. The major limiting factor in coupling is the uneven profile of mode field of the single-mode fiber and waveguide, and the accuracy in transverse realignment between them. By using single-mode fiber microlens, the transverse field can be evenly adjusted. By using 2-D etched silicone V groove as a micromodulator, the alignment accuracy between them can be fine tuned. The maximum value for the coupling is measured at 64%, and the coupling has also been found very stable.

* Numbers in margins indicate foreign pagination. Commas in numbers indicate decimals.

1 Changchun College of Optics and Fine Mechanics.

2 Changchun Institute of Physics, Academia Sinica.

II. MODE COUPLING THEORY

1. The Conducting Surface of Single-Mode fiber

When light transmits in single-mode fiber, a complicated mathematical expression of the single-mode fiber conducting surface can be obtained by a group of Maxwell equations [1]. When the difference in refractive index between inner core and covering layer $n_1-n_2<<1$, i.e. when it meets the condition of weak conducting surface, the transverse vector in the electrical field in the core would be much smaller than the horizontal vector. We can disregard the group of Maxwell equations and use wave equations instead to deal with the conducting surface field.

It has been shown, HE_{11} is the major factor for leaping single-mode fibers [2]. The electrical field of linearly polarized HE_{11} mode has a similar profile as the cross section of the single-mode fiber in Gauss field. Therefore, Gauss field can be used to approximate the single-mode fiber.

$$\psi(x)=\sqrt{\frac{2}{\pi}}\;\frac{1}{w_0}\exp\left(-\frac{x^2}{w_0^2}\right) \tag{1}$$

W_0 is wave width index.

2. The Conducting Surface of Planar Waveguide

In order to completely describe the conducting surface of waveguide media, the group of Maxwell equations has to be solved. By solving the wave equation, a planar waveguide mode can be subdivided into TE mode or TM mode. TE mode contains only Ey, Hx, Hz. TM mode contains Hy, Ex and Ez [3]. For TE mode,

$$\frac{\partial^2 E_y}{\partial x^2}=(\beta^2-n^2k^2)E_y \tag{2}$$

By solving (2), nonsymmetric planar waveguide TE mode profile can be obtained.

$$\phi(x) = E_y = A\left(\frac{x}{w}\right)\exp\left(-\frac{x^2}{w^2}\right) \tag{3}$$

ω is width index of mode field strength in planar waveguide TE.

3. Coupling Efficiency

By defining coupling [4], and by integrating the profile of incoming light beam wave and that of waveguide mode field, an mathematical expression of coupling efficiency can be obtained

$$\eta_m = \frac{\left[\int_{-\infty}^{+\infty}\psi(x)\phi_m^*(x)\,dx\right]^2}{\int_{-\infty}^{+\infty}\psi(x)\psi^*(x)\,dx\int_{-\infty}^{+\infty}\phi_m(x)\phi_m^*(x)\,dx} \tag{4}$$

By substituting (4) with (2) and (3), we can obtain

$$\eta = \frac{4ww_0^2}{\pi(w^2+w_0^2)^{1/2}}\,e^{-(w_0\sqrt{2}\,a/w)^2}\left\{e^{-a^2} + a\sqrt{\pi}\,[1+\mathrm{erf}(a)]\right\}^2 \tag{5}$$

in which $a = \frac{wx'}{w_0(w_0^2+w^2)^{1/2}}$, x' is the aligning discrepancy between the fiber optics and the waveguide, when $x' = w/\sqrt{2}$ there will be a match in the peak values in the two field profiles, a maximum coupling efficiency will result.

III. THE DESIGN, BUILDING AND TEST OF OPTICAL PARTS

A coupler which gives the best available coupling efficiency has been designed(fig.1). A microlens is placed at the end of transmission fiber A, two different etched 2-D silicone V grooves are used as positioning modulator. The transmission fiber A is placed at the shallow groove, while an adjusting fiber B is placed at the deeper one. Two of them intersects. Fiber A can be fine tuned in vertical direction via tapperep fiber B.

1. Single-Mode Planar Waveguide

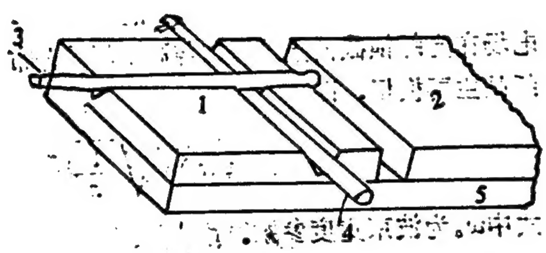
A equation that corresponds to (3)

$$N^2 = n_0^2 - \frac{4m+3}{kd}\sqrt{\Delta n^2} \qquad (6)$$

n_0 is the refractive index of the surface of the waveguide, $\Delta n^2 = n_0^2 - n_s^2$, n_s is the refractive index at the bottom, d is the characteristic value in diffusion thickness. Using m=0 and m=1, the condition for the single-mode should be

$$m = 0, \quad n_s^2 = n_0^2 - \frac{3}{kd_0}\sqrt{\Delta n^2} \qquad (7)$$

$$m = 1, \quad n_s^2 = n_0^2 - \frac{7}{kd_1}\sqrt{\Delta n^2} \qquad (8)$$



Key: 1. 2-D silicone V grooves; 2. single-mode planar waveguide; 3. transmitting optical fiber A; 4. tapperep adjust fiber B; 5. regular glass slides.

Fig.1 A schematic diagram of proposed fiber -to-planar waveguide coupler using two -dimentional silicon grooves.

Hence, the condition for nonsymmetric planar waveguide is

$$\frac{3}{2\pi} < \frac{d}{\lambda}\sqrt{\Delta n^2} < \frac{7}{2\pi} \qquad (9)$$

Based on (9), interior diffusion is used to make single-mode planar waveguides in our experiment. A 40nm Ti membrane is sprayed onto the bottom of $LiNbO_3$ and is left at 1000°C diffusion oven for 9 hours, thus a single-mode planar waveguide with Gauss refractive index profile is obtained.

End polishing of the waveguide is also very important. M10, M7, M3 have been used for preliminary polishing. M1 is used for final polishing. In the end, a smooth, flat waveguide end is obtained.

A near field profile of the single-mode planar waveguide is drawn by CCD detection system. The width index for TE mode waveguide field strength is calculated as 2.02 μm. Each small square of X axis is equivalent to 2 CCD unit, i.e. 28 μm. Y axis shows the detected light intensity. The right side indicates the surface of the waveguide. The magnification of the object lens sandwiched between the waveguide and CCD is 39.

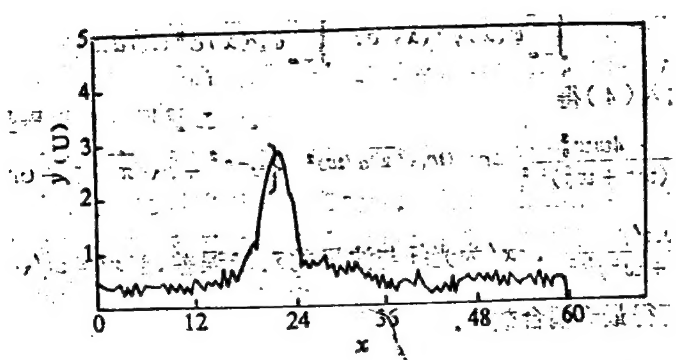


Fig. 2 Near-field profile of single-mode planar waveguide.

2. V Shaped 2-D Silicone Groove and Tapperep Fiber

According to the semiconductor processing principle [5], if the (100) side of silicone is treated with corrosive reagent, V shaped groove will form along the (111) side. The depth of the V-shaped groove is only contingent upon the

width of light field. V-shaped 2-D silicone groove can be made with a single board.

The depth of the groove h_1 and the width s1 has a relation $h_1 = s_1/\sqrt{2}$. The width relates to the outer diameter D of optical fiber, i.e $s_1 = D/\sin_\theta$. The groove is designed in such a way so that transmitting optical fiber and tapperep fiber intersect as in fig.3b. In our $h_2 = a_1 + (1+\sqrt{3})a$ experiment, the outer diameter of the optical fiber is 125 μm, the width of the shallow groove is 153 μm, the width of deep groove is 209 μm.

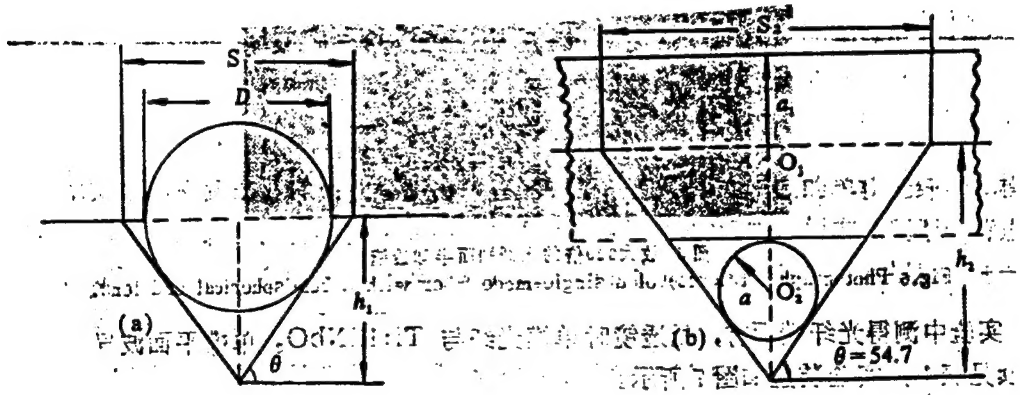


Fig.3 Relationship between etched Si-V groove and outer diameter of optical fiber for shallow groove (a) and deep groove (b).

A light inscribed cover membrane plate is made with two grooves above. A 600nm SiO_2 protective layer is formed on the (100) side of the silicone. A SiO_2 piece about the size of the cover membrane is removed from the silicone by the light inscribing method. Subsequently, it is placed into 80°C KOH solution. A V-shaped 2-D groove is formed 4 hours

later. The composition of the solution is KOH:Isopropyl alcohol: pure water= 19% : 13.3% : 67.7%.

The tapperep fiber is made with buffered HF solution with a component ratio $HF:NH_4F:H_2O$=3ml : 6g : 10ml, as it is depicted in fig.4

$$\Delta h = x_2 - x_1 = \frac{y_2 - y_1}{l}(r_b - r_a)$$

In our experiment, the radius of the single-mode fiber is $2r_b$=125 μm. After the corrosive treatment $r_a = r_b/2$, use l=15,00 μm, $h = 2.08\times10^{-3}(y_2 - y_1)$. This implies that when the tapperep fiber moves 1 mm forward or backward, the transmitting fiber moves 2 μm in the vertical direction.

3. The Microlens End of the Single-Mode Fiber

In our experiment, a leap type single-mode fiber with 8 μm inner diameter and 125 μm of outer diameter is used. It is first treated with HF slightly, and then cut with diamond to produce a flat, smooth end.

A hemispherical end lens is formed (fig.5) by electrical sparks. The measured radius of this lens is 39 μm, focal length is 74 μm, the distance from the end of the optical fiber is 39.6 μm.

Far field profile [6] of the single-mode fiber with a lens or without a lens is shown in fig. 6(b) and (a). The width of emitting light beam is 3.04 μm and 4.84 μm respectively.

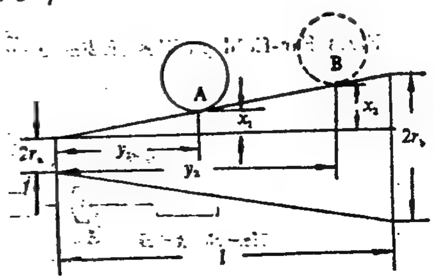


Fig.4 A pattern of tapperep fiber.

4. The Measurement of the Coupling Efficiency

The coupling efficiency between the single-mode fiber with or without an end lens and Ti:$LiNbO_3$ single-mode planar waveguide is measured and listed in table 1. The set-up used for measuring is shown in fig.7.

Since the end lens of the singe-mode fiber condensed the light beams used, the coupling efficiency can be increased 1.43 magnitude in theory, this agrees with our experimental values. The total deficit in "fiber-waveguide (1 cm)-output lens" is 4.4 dB. The data listed in table 1 are the maximum values.

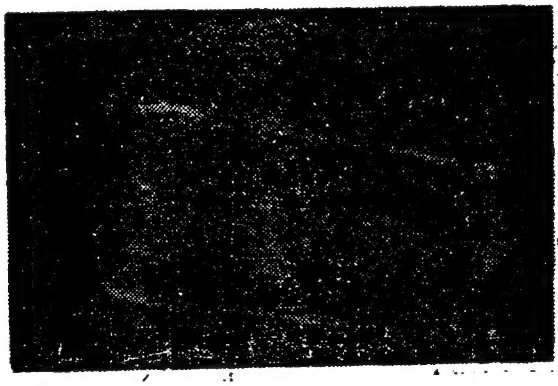
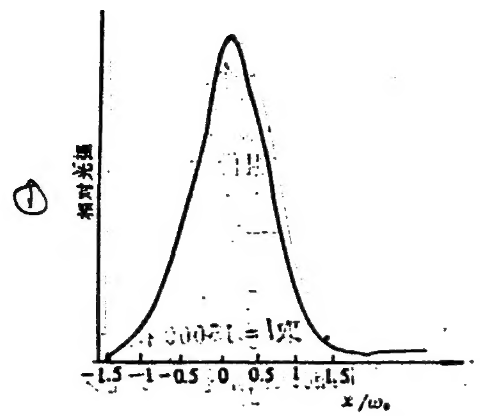
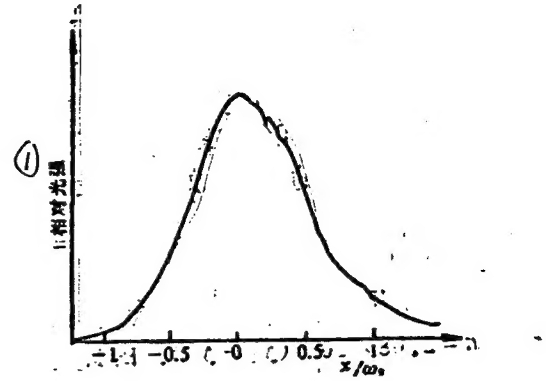


Fig.5 Photograph (at ×320) of a single-mode fiber with a hemispherical end lens.



(a) In the absence of end lens



(b) In the presence of end lens

Fig.6 Far-field profiles of single-mode fiber with no lens (a) and with a lens (b)

Key: 1. Relative Light Intensity.

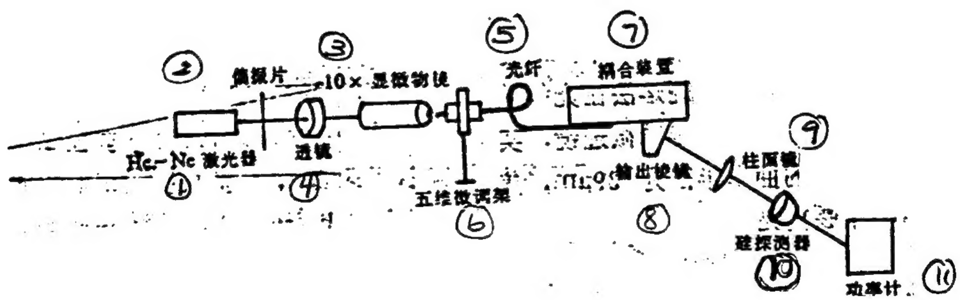


Fig.7 Set-up for measuring the coupling efficiency of beam

Key: 1. He-Ne laser generator; 2. polarizer; 3. 10X object lense; 4. lens; 5. optical fiber; 6. 5-D micro-adjuster; 7. coupling apparatus; 8. output prism; 9. lens; 10. silicone detector; 11. power meter.

IV. CONCLUSION

A very practical coupling set-up for the single-mode fiber and the single-mode planar waveguide is designed based on the mode coupling theory. There are still some questions to be addressed, i.e. how to improve technical skill in spraying a layer of anti-reflective membrane to reduce wearing and to increase the coupling efficiency.

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REFERENCES

〔1〕周树同，光纤理论与测量，复旦大学出版社(1988).
〔2〕D.Marcuse, J.Opt.Soc. Amer., 68(1), 103(1978).
〔3〕金锋，范俊清，集成光学(上册)，国防工业出版社(1981).
〔4〕陈益新等，集成光学，上海交通大学出版社(1985).
〔5〕黄汉尧等，半导体器件工艺原理，国防工业出版社(1980).
〔6〕P.D.Bear, Appl.Opt., 19(17), 2906(1980).

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